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Alien species in the Finnish weed flora

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The present study aimed at assessing the invasion of alien weed species in Finland based on a review of their occurrence in the Finnish weed flora. The evaluation was conducted for the three phases of the invasion process, i.e. introduction, naturalization and invasion. The literature review revealed that 815 alien weed species occur in Finland of which 314 are regarded as naturalized. Based on their occurrence in different climate zones, the risk of naturalization of new harmful alien weed species was deemed low for those species not currently found in Finland, but higher for species occurring as casual aliens in Finland. In the latter group, 10 species of concern were detected. Exploration of the distribution patterns of naturalized species within Finland revealed species occupancy to be dependent on the residence time of the species. Established neophytes can be expected to extend their ranges and to increase occupation of agricultural habitats in the future.

Key words: climate change, Finland, invasive species, weed management

Introduction

Invasive alien plant species have been of recent concern as they represent a considerable environmental challenge, causing negative impacts on ecological communities in their introduced ranges (Mack et al. 2000). In agricultural habitats, which are particularly susceptible to invasions (Chytrý et al. 2009), alien plants can assume the status of harmful weeds. Since the control of new weeds is more successful the earlier it is conducted (Simberloff 2009), anticipation of invasion of potentially harmful weed species is important. The anticipation requires early recognition of potential invaders based on information on their climatic and environmental preferences as well as their weed status outside their current range (Pheloung et al. 1999).

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The process of invasion of an alien species can be divided into three phases (see Richardson et al. 2000 for terminology): introduction (transportation by humans across a major geographical barrier), naturalization (surmounting the abiotic and biotic barriers regulating regular reproduction) and invasion (producing reproductive offspring in areas distant from sites of introduction). Different factors limit the distribution or abundance of species during the different phases of invasion. For introduction, the transportation of propagules, i.e. propagule pressure (Lockwood et al. 2005, Colautti et al. 2006) is a major issue. Naturalization is primarily controlled by climatic factors, suggested by decline in species richness of alien plants with increasing latitude (Sax 2001, Pyšek and Richardson 2006). For invasion, factors related to habitat such as habitat availability (Pyšek et al. 2005, Chytrý et al. 2009, Jauni and Hyvönen 2010), disturbance regime (Hobbs and Huenneke 1992, Kiss and Béres, 2006), resource availability (Davis et al. 2000) and residence time (Pyšek and Jarošík 2005, Williamson et al. 2009), as well as the characteristics of the species (e.g. Thompson et al. 1995, Pyšek and Richardson 2007), are of importance. A comprehensive evaluation of the risk of invasion should include consideration of the species representing each of the three phases of invasion and the factors controlling them.

Regarding weed invasions in northern regions, climate change is of major concern. In general, the relationship between climate change and alien plant invasions is complex and the impact is difficult to predict (Dukes and Mooney 1999, Vilá et al. 2007, Hellmann et al. 2008, Walther et al. 2009, Bradley et al. 2010). Climate change in Finland can be assumed to encourage invasions of weed species into agricultural habitats for several reasons. Firstly, climatic factors have been shown to be the major factor limiting plant species richness in Fennoscandia (Grytnes et al. 1999) and arable weed species richness in European climate gradient (Glemnitz et al. 2006). As a result, several noxious weed species (Schroeder et al. 1993) are currently missing from Finland. Secondly, climate change is predicted to alter the distribution patterns by allowing plant species to broaden their distribution areas (Sætersdal et al. 1998, Milberg and Andersson 2006). Thirdly, climate change is predicted to extend the growing season and change the structure of crop production (Peltonen-Sainio et al. 2009), thus affecting the invasibility (see Rejmánek et al. 2005) of arable habitats to different species. Taken together these changes can be expected to affect all phases of the species invasion process.

The present study aimed at examining the invasion of alien agricultural weed species in Finland by reviewing the occurrence and distribution of European weed species in Finland. The species occurrence (established or casual) in Finland was used as a measure of the success of introduction. The risk of naturalization of the species in Finland was studied by exploring the distribution and weed status of non-naturalized species, i.e. species currently not found in Finland as well as casual aliens, in different European climate zones. The risk of invasion was evaluated by exploring the distribution patterns of naturalized species found in Finland as well as the invasiveness and the habitat preference of all species found in Finland. The study provides new information on the distribution of alien plant species and the risk of invasion in Finland, which have been limited to date (see however Jauni and Hyvönen 2010).

Material and methods

Weed flora of Europe

The species composition of the European weed flora was defined based on the species lists provided by Häfliger & Hildemar (1980 and 1981), Häfliger et al. (1982), Williams (1982), Hanf (1983) and Williams & Hunyadi (1987). As a result, a list of 2412 species or taxa was composed. After exclusion of the subspecies and species defined at genus level only, the number of species was reduced to 2220 (see Table 1).

Table 1. Number of weed species found in Europe and Finland classified according to their residence time and weed importance status.

Importance as a weed[a]	Weed species of Europe						
	Species found in Finland					Species not found in Finland	Total
	Alien			Native	Total		
	Archaeophyte	Established neophyte	Casual neophyte				
1	19	35	163	125	342	498	840
2	47	48	173	123	391	299	690
3	77	55	114	90	336	98	434
4	24	5	10	7	46	4	50
No information	2	2	41	5	50	156	206
Total	169	145	501	350	1165	1055	2220

[a]1: Of no importance as a weed; 2: Only of minor importance; 3: Only important in a few situations, although it may be widespread as a minor weed species; 4: An important competitive weed occurring in many crops and many situations (Williams 1982, Williams and Hunyadi 1987).

Species found in Finland

The occurrence (presence or absence) and the alien status (alien or native) of the 2220 weed species in Finland were explored with the aid of information provided in the Field Flora of Finland (Hämet-Ahti et al. 1998) and the atlas of Finnish vascular plants (Lampinen and Lahti 2009**).**

The same data sources were used for exploring the taxonomy, distribution, residence time and habitat preference of the species classified as aliens in Finland (815 species, see Table 1). The occurrence (i.e. presence or absence) and residence status (i.e. native (native to Finland), archaeophyte (introduced before 17th century), established neophyte (introduced after 17th century) and casual neophyte) of the species in the 20 biogeographical provinces of Finland (e.g. Hämet-Ahti et al. 1998) were recorded (see Fig. 1). The distribution patterns among archaeophytes, established neophytes and casual neophytes were examined by correlating (Pearson correlation coefficient) the number of biogeographical provinces occupied by the species of each species group. Following the definition of Hämet-Ahti et al. (1998), species introduced into Finland before the early 17th century were classified as archaeophytes and after that date as neophytes. Habitats were allocated to seven categories (1. agricultural, 2. ruderal, 3. gardens, 4. shores and ditches, 5. rocky or sandy dry habitats, 6. forests and 7. bogs, mires and fens) for which species occurrences were recorded. The information on habitat preference was not available for the species found in the atlas of Finnish vascular plants (303 species) only.

The information on the origin (European or extra-European) of the species was obtained from Hämet-Ahti et al. (1998) and DAISIE (2009), and the invasiveness of the species in Northern Europe in NOBANIS (2009). In the examination of invasiveness, a record was made of the numbers of species classified as 'invasive' in Finland and other countries in the NOBANIS database.

Species not found in Finland

The information on the distribution of the species in European countries or regions (presence or absence)

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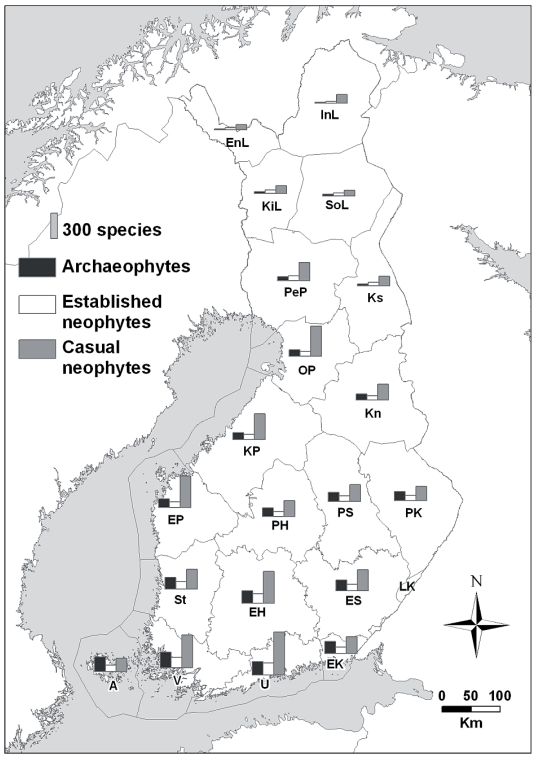

Fig. 1. Distribution of the 815 alien weed species found in Finland (see Table 1) in three categories representing different residence times by biogeographical provinces of Finland. Key for the provinces: A=Ahvenanmaa, V=Varsinais-Suomi, U=Uusimaa, EK=Etelä-Karjala, St=Satakunta, EH=Etelä-Häme, ES=Etelä-Savo, LK=Laatokan Karjala, EP=Etelä-Pohjanmaa, PH=Pohjois-Häme, PS=Pohjois-Savo, PK=Pohjois-Karjala, KP=Keski-Pohjanmaa, Kn=Kainuu, OP=Oulun Pohjanmaa, PeP=Perä-Pohjanmaa, Ks=Koillismaa, KiL=Kittilän Lappi, SoL=Sompion Lappi, EnL=Enontekiön Lappi and InL=Inarin Lappi.

was obtained from Häfliger and Hildemar (1980 and 1981), Häfliger et al. (1982), Williams (1982) and Williams and Hunyadi (1987). Since the spatial accuracy of the information on the occurrence of the species varied among data sources, the information was combined at the level of three climate zones as follows: 1) Northern Europe (Finland, Sweden, Norway, northern Britain, Ireland and Iceland), 2) Central Europe (Denmark, northern Germany, Netherlands, Belgium, southern Britain and northern France) and 3) Southern Europe (Austria, southern France, southern Germany, Italy, Portugal, Russia, Spain and Switzerland).

The information on the importance as a weed species provided by Williams (1982) and Williams and Hunyadi (1987) was used to define the weed status of the species in the three climate zones. The species were classified as: 1: Of no importance as a weed, 2: Only of minor importance, 3: Only important in a few situations, although possibly widespread as a minor weed species and 4: An important weed occurring in many crops and many situations. The invasiveness of the species was defined by NOBANIS-databases, as above.

Results

Species found in Finland

The literature review revealed the total number of weed species in Europe to be 2220 (Table 1), of which 1165 (52.5%) were found in Finland. The majority of the species (815 species equating with 36.7% of all European species) found in Finland were aliens, of which 314 can be regarded as naturalized, i.e. they belong to the archaeophytes or naturalized neophytes (see Appendix in Supplementary material).

The alien weed species found in Finland represented 69 families and 375 genera (Table 2). The most species rich families were the Asteraceae (104 species), Poaceae (93), Fabaceae (76) and Brassicaceae (71). The most species rich families were much the same among the three alien species groups. However, the Poaceae and Fabaceae had slightly greater shares in casual neophytes compared with the other groups (Table 2). The majority of the species were of European origin, the share being highest (98.2%) in archaeophytes. Archaeophytes also preferred agricultural habitats

Table 2. Taxonomy, origin, invasiveness and habitat preference of the alien weed species found in Finland in three categories representing different residence times in Finland.

	Archaeophytes	Established neophytes	Casual neophytes	Total
Taxonomy				
Number of species	169	145	501	815
Number of genera	113	107	279	375
Number of families	33	35	58	69
Most important families				
Asteraceae	20 (11.8)	19 (13.1)	65 (13.0)	104 (12.8)
Poaceae	15 (8.9)	15 (10.3)	63 (12.6)	93 (11.4)
Fabaceae	9 (5.3)	12 (8.3)	55 (11.0)	76 (9.3)
Brassicaceae	15 (8.9)	16 (11.0)	39 (7.8)	71 (8.7)
Lamiaceae	10 (5.9)	9 (6.2)	22 (4.4)	41 (5.0)
Scrophulariaceae	12 (7.1)	8 (5.5)	16 (3.2)	36 (4.4)
Caryophyllaceae	8 (4.7)	7 (4.8)	20 (4.0)	35 (4.3)
Apiaceae	5 (3.0)	3 (2.1)	22 (4.4)	30 (3.7)
Chenopodiaceae	7 (4.1)	3 (2.1)	18 (3.6)	28 (3.4)
Boraginacceae	7 (4.1)	5 (3.5)	10 (2.0)	22 (2.7)
Cichoriaceae	6 (3.6)	4 (2.8)	12 (2.4)	22 (2.7)
Polygonaceae	7 (4.1)	3 (2.1)	11 (2.2)	21 (2.6)
Ranunculaceae	5 (3.0)	3 (2.1)	13 (2.6)	21 (2.6)
Origin				
European	166 (98.2)	131 (90.3)	447 (89.2)	744 (91.3)
Extra-European	3 (1.8)	14 (9.7)	54 (10.8)	71 (8.7)
Invasiveness				
NOBANIS[1)]	12 (2)	56 (25)	32 (5)	100 (32)
Habitat[2)]				
Agricultural	147 (87.0)	56 (38.6)	46 (23.2)	249 (25.8)
Ruderal	127 (75.1)	126 (86.9)	169 (85.4)	422 (43.7)
Gardens	39 (23.1)	41 (28.3)	81 (40.9)	161 (16.7)
Shores, ditches	29 (17.2)	30 (20.7)	3 (1.5)	62 (6.4)
Rocky or sandy dry habitats	24 (14.2)	11 (7.6)	-	35 (11.1)
Forests	20 (11.8)	14 (9.7)	-	35 (11.1)
Bogs, mires, fens	2 (1.2)	-	-	2 (0.6)

[1)]The number of species classified as 'invasive' in the NOBANIS database (NOBANIS 2009). The number of species classified as 'invasive' in Finland in parentheses.

[2)]Data available only for 198 casual neophyte species.

more than did the established or casual neophytes (Table 2).

The share of species belonging to the category of highest importance as weeds was greater in archaeophytes (14.2%) than in established (3.5%) or casual neophytes (2.0%) (Table 1). The species belonging to the category of highest importance as a weed included ten casual neophytes (*Amaranthus retroflexus* L., *Anagallis arvensis* L., *Avena sterilis* L., *Chrysanthemum segetum* L., *Cynodon dactylon* (L.) Pers., *Datura stramonium* L., *Digitaria sanguinalis* (L.) Scop., *Echinochloa crus-galli* (L.) P. Beauv., *Lolium temulentum* L. and *Papaver rhoeas* L.). All of the ten species belonged to the category of highest importance as a weed in the western climate zone of Europe, three species (*D. sanguinalis*, *E. crus-galli*, *P. rhoeas*) in the southern, one (*P. rhoeas*) in the central and none in northern climate zone of Europe. The share of invasive species based on the classification of the NOBANIS

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database was the greatest (38.6%) for established neophytes (Table 2).

The number of species found in biogeographical provinces of Finland varied considerably (Fig. 1). In general, the number of species was higher in southern than in northern Finland. The highest numbers of archaeophytes were found in the provinces of Varsinais-Suomi and Ahvenanmaa, whereas Uusimaa province harboured the highest numbers of established and casual neophytes, 117 and 420, respectively. The number of casual neophytes was high also in the provinces situated in the coastal region (Fig. 1). The correlation among the number of biogeographical provinces occupied by species was higher between archaeophytes and established neophytes ($r = 0.820$, $p < 0.001$) than between archaeophytes and casual neophytes ($r = 0.614$, $p < 0.01$) or between casual and established neophytes ($r = 0.787$, $p < 0.001$). Casual neophytes occupied fewer provinces than established neophytes or archaeophytes (Fig. 2).

Species not found in Finland

Of the 2220 weed species of Europe, 1055 (47.5%) were not found in Finland (Table 1). Only four of the species belonged to the category of highest importance as a weed (Table 3), and they belonged to this category only in the western climate zone of Europe, i.e. in Spain and Portugal.

Thirteen of the species (*Ailanthus altissima* (Mill.) Swingle*, Carpobrotus edulis* (L.) N.E.Br.*, Rhododendron ponticum* L.*, Barbarea intermedia* Boreau*, Cenchrus echinatus* L.*, Citrullus colocynthis* (L.) Schrad.*, Elodea nuttallii* (Planch.) H.St. John*, Euphorbia peplus* L.*, Lagarosiphon major*

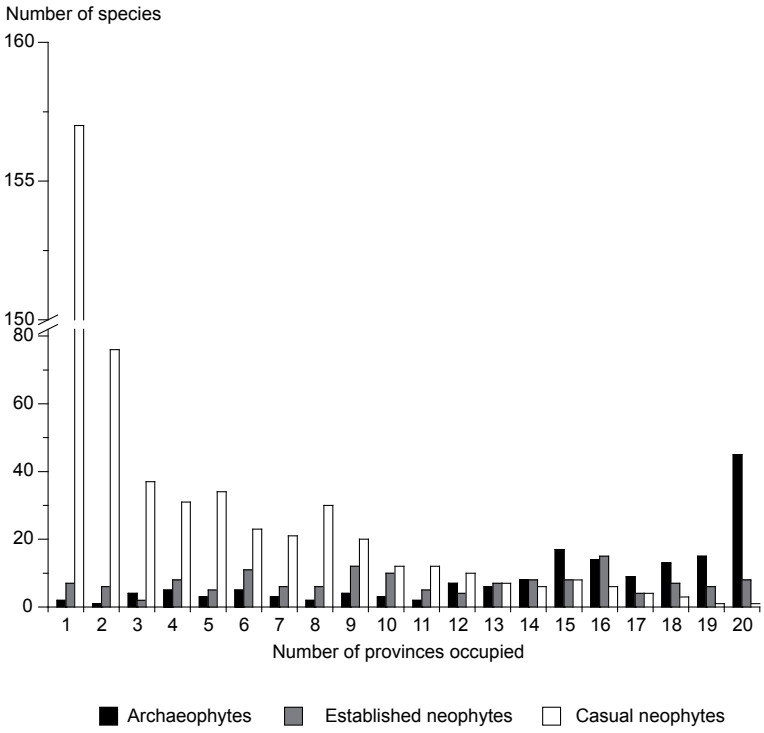

Fig. 2. Number of biogeographical provinces occupied by alien weed species in three categories representing different residence times in Finland.

Table 3. Number of weed species 'not found in Finland' and the most noxious species by climate zones of Europe classified according to their weed importance status.

Importance as a weed[a]	Climate zone[b]			
	Northern	Central	Southern	Western
1	872	869	820	599
2	26	23	60	225
3	1	7	19	71
4	-	-	-	4
No information	156	156	156	156
Most noxious species				
Cyperus rotundus	1	1	3	4
Cyperus esculentus	1	1	2	4
Eichornia crassipes	1	1	2	4
Diplotaxis catholica	1	1	1	4

[a]1: Of no importance as a weed; 2: Only of minor importance; 3: Only important in a few situations, although it may be widespread as a minor weed species; 4: An important competitive weed occurring in many crops and many situations

[b]Northern: Finland, Sweden, Norway, N. Britain, Ireland, Iceland; Central: Denmark, N. Germany, Netherlands, Belgium, S. Britain, N. France; Southern: S. Germany, Austria, Switzerland, Italy, S. France; Western: Spain, Portugal

(Ridl.) Moss, *Lycium barbarum* L., *Myriophyllum aquaticum* (Vell.) Verdc., *Nymphoides peltata* (S.G.Gmel.) Kuntze, *Oxalis stricta* L., *Samubucus nigra* L.) not found in Finland were regarded as invasive in the NOBANIS database. However, only three of them (*B. intermedia*, *L. barbarum* and *O. stricta*) are found in agricultural habitats according to information provided by NOBANIS and none belonged to the category of highest importance as a weed.

Discussion

This study aimed at assessing the invasion of Finland by alien agricultural weed species. The evaluation was conducted for the three phases of the invasion process, i.e. introduction, naturalization and invasion.

The success of introduction of alien agricultural weeds into Finland was explored by reviewing the occurrence of European weeds found in Finland. The first phase in this assessment was definition of the weed flora of Europe, which resulted in the list of 2220 species. The species number can be regarded as high in comparison with the 768 species reported earlier by Glemnitz et al. (2006) or compared with those reported in national weed surveys, for example the 168 species from Finland (Salonen et al. 2001) and 224 species from Denmark (Andreasen and Stryhn 2008). The high number of weed species in the European weed flora was partly due to inclusion of plant species occupying habitats other than agricultural ones (see Table 2), in contrast to previous studies.

The number of alien weed species detected in the present study (815) can also be regarded as high compared with the above figures, even though the number is low compared with the recently updated number of 5789 alien plant species in Europe (Lambdon et al. 2008, Pyšek et al. 2009). The number of alien weed species found in Finland was enhanced by the inclusion of all observations on the species occurrence in the study, regardless of frequency of occurrence. The high share of casuals among the alien species found in Finland (501 out of 815 species) indicates that most of them were found in Finland only occasionally (see Lampinen and Lahti 2009). The finding suggests that the immigration of propagules (i.e. propagule pressure,

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see Lockwood et al. 2005) of alien weed species has been effective, but the circumstances for establishment of permanent populations (i.e. naturalization) have not been favourable for most alien weed species in Finland.

In some respects the characteristics of naturalized alien species found in Finland followed the European patterns. In comparison with European averages reported by Lambdon et al. (2008) and Pyšek et al. (2009), the alien weed flora of Finland included fewer naturalized aliens (38.5% vs. 65%) and fewer species of extra-European origin (8.7% vs. 49%) compared with European naturalized aliens. However, the most species-rich families (Asteraceae, Poaceae, Fabaceae and Brassicaceae), excluding the Rosaceae, and the most preferred habitats (ruderal and agricultural), were the same. The differences in the share of naturalized species of all alien species and the origin of the species can be regarded as an indication of a shorter invasion history of Finland compared with most other European countries (Lambdon et al. 2008). This suggests the pressure of naturalization of alien species in Finland will continue into the future.

Regarding naturalization of alien weed species, the major concerns are the aliens occurring as casuals in Finland and species not currently found in Finland. The literature review showed the total species number to be high, but the number of noxious weed species remained low in species groups, 10 and 4, respectively. Furthermore, the exploration of their occurrence in European climate zones revealed that only *Papaver rhoeas* belonged to the category of highest importance as a weed in the climate zone situated closest to Finland, i.e. Central Europe. These findings suggest that the risk of naturalization of the harmful alien agricultural weed species, in terms of species not found in Finland, can be regarded as minor but is greater for species occurring in Finland as casual aliens. However, the relatively old data sources used for the evaluation of species importance as a weed (Williams 1982, Williams and Hunyadi 1987) may underestimate the risk for some individual species such as *Ambrosia artemisiifolia* (Kiss and Béres 2006) and *Heracleum mantegazzianum* (Pyšek et al. 2007), which have become noxious invasive weeds in the Central Europe in recent decades. Williams (1982) and Williams and Hunyadi (1987) classified those species as 'only of minor importance as a weed'. Therefore, the use of updated databases such as DAISIE (2009) and NOBANIS (2009) is of importance in the evaluation of the risk of naturalization as well as of invasion.

Invasion, i.e. spread of species, was evaluated by exploring the distribution patterns of species within Finland. The exploration showed that the majority of the established alien species occur only in a limited range in Finland, the pattern found in ruderal plants at a smaller spatial scale earlier (Hanski 1982). The limitation in the range size might be for several reasons, such as dispersal limitation (Forcella 1985), the length of invasion history (Chytrý et al. 2009, Williamson et al. 2009), unsuitable climatic conditions (Grytnes et al. 1999) or the lack of preferred habitats (Essl et al. 2009). The higher number of alien weeds recorded in coastal regions compared with inland indicates the importance of invasion history along with a south-north climate gradient in our data. We found species occupancy and habitat preference of the species to be dependent on the residence time of the species. Recently, it was shown that it often takes at least 150 years for the maximum distribution to be reached by a naturalized alien plant species (Williamson et al. 2009) and archaeophytes and neophytes do not differ in their habitat preference (Chytrý et al. 2008). This suggests that at least archaeophytes, which by definition were introduced into Finland as early as before the early 17th century, have mostly already reached their final distribution and their preferred habitats in Finland. In contrast, established neophytes can be expected to extend their ranges even without major changes in the limiting factors and to increase the occupation of agricultural habitats in the future. Climate change may broaden the distribution areas of both species groups in the future (Walther et al. 2009).

Climate change has been of concern recently with regard to alien weed invasions in Finland. Climate change will initially affect the naturalization and invasion of alien weed species. The predicted changes in temperature (e.g. Jylhä et al. 2004) and the consequent extension of the grow-

ing season will affect positively the maintenance of the populations of many alien weeds (Patterson 1995), and thus enhance naturalization of alien weed species. In addition to direct climate impacts, alien weed invasion will be promoted by changes in crop production (Peltonen-Sainio et al. 2009). For example, habitat availability for several harmful casual aliens will be enhanced by an increase in the area of autumn-sown cereals (*Avena sterilis* and *Lolium temulentum*) and the introduction of maize cropping (e.g. *Amaranthus retroflexus*, *Cynodon dactylon*, *Digitaria sanguinalis* and *Echinochloa crus-galli*) (Schroeder et al. 1993, Pyšek et al. 2005). However, the distribution of some of the casual neophytes (e.g. *Anagallis arvensis* and *Papaver rhoeas*) will be limited by their preference for calcareous soils (e.g. Andreasen and Skovgaard 2009), which are limited in area in Finland. The approach used for the assessment of invasion in the present study provides only a general overview of the topic. More accurate predictions on the success of populations and the shifts in the distributions will require experiments and modelling approaches involving species-specific habitats and climate requirements (Bradley et al. 2010).

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